CHAPTER NINE

MANUFACTURING COST ESTIMATING

CONTENTS

MANUFACTURING COST ESTIMATING

OBJECTIVE

This chapter describes the structure of manufacturing costs and the various techniques used to estimate cost. Emphasis is placed on understanding the basis for potential variability in how individual contractors may present cost information. The impact of standards and the learning, or manufacturing improvement curve, is described to help the Program Manager (PM) analyze manufacturing efficiency and improvement. The final sections deal with techniques which may be applied by the PM to establish programs for the management and control of manufacturing costs. The objective is to establish an understanding of the composition of manufacturing costs and discuss the manufacturing cost estimating process.

INTRODUCTION

Cost is one of the primary measures of management effectiveness, along with performance and schedule, applied to defense programs. The focus of this chapter is on the identification and characterization of manufacturing costs as they are estimated and incurred by defense contractors. Certain government and contractor policies and actions, which can have significant impact on manufacturing cost, need to be considered during the planning and execution of weapon system development programs. These activities include decisions on production rate, long lead funding, and capital investment. The final perspective developed in this chapter concerns the use of cost as a management planning and system design tool. With the increasing emphasis within the DOD on system affordability, cost (both manufacturing and support) must be considered as a design and program planning criterion throughout the acquisition process. Only by explicit consideration of cost can the program manager obtain the optimal mix of weapon system performance and weapon system acquisition cost and operating and support cost.

NATURE OF MANUFACTURING COSTS

The cost to manufacture a weapon system or equipment results from a combination of the engineering design, the physical facility (factory, personnel, and equipment) used to build the design and the management efficiency of the operation. This is illustrated in Figure 9-1. As such, the manufacturing cost for a product should be viewed within the context of the factory in which it will be built. Where the place of manufacture is not yet defined, assumptions as to the physical facility and efficiency will need to be made to support the estimating activity.

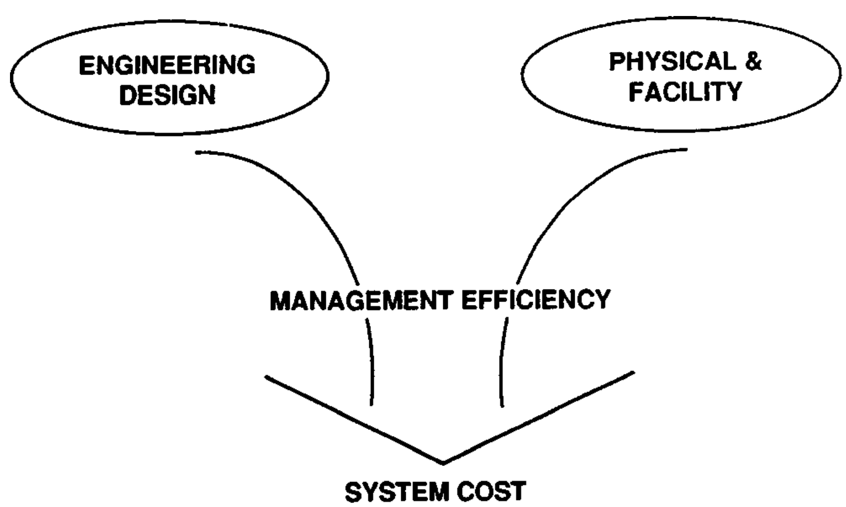

Figure 9-1 Manufacturing Cost Genesis

Direct and Indirect Costs

A classic division of manufacturing cost is between direct and indirect costs. A direct cost can be defined as any cost that is specifically related to a particular final cost objective, but not necessarily limited to items that are incorporated in the end item as material or labor. The majority of the direct cost is involved in the direct labor and direct material used in designing and fabricating the system or equipment. An indirect cost is one which is not directly identified with a single final cost objective, but is identified with two or more final cost objectives, or with at least one intermediate cost objective, on the basis of benefits accruing to the several cost objectives. An example of indirect cost is manufacturing overhead which may include such things as supervision, material handling and production engineering support. The division of effort between direct and indirect is a function of the particular contractor's cost accounting standards and the relationship of the specific contract to the total manufacturing effort within the facility. It is imperative that the program office and supporting government personnel develop a clear understanding of the accounting and cost estimating approach in use by the contractor.

ANALYSIS OF DIRECT COSTS

Classifying Direct Costs

While there are general guidelines established in Cost Accounting Standards and FAR Part 31, the contractor is given some latitude in classifying costs as direct or indirect. In all cases, it is very important that costs are classified in a consistent manner within a specific contractor cost accounting system. When comparing one firm with another, remember that practice in direct cost classification does vary among contractors. Typically, such items as manufacturing labor, production test and design engineering are classified as direct costs. In the production phase, some design engineering effort in support of production may be classified as indirect. Quality control is classified as direct by some contractors and indirect by others.

Importance of Direct Costs

Direct costs are important elements of cost, often accounting for 30 to 60 percent of total cost. But equally important, direct cost is usually the basis for allocating most of the indirect (overhead) cost. Direct costs of material, manufacturing labor, and engineering labor, in particular, often serve as bases for the application of costs from overhead pools. If we define price to the government as the total of direct cost, indirect cost, general and administrative cost, cost of facilities capital and profit, a change in direct cost can produce a much larger change in price to the government.

Fixed and Variable Cost

Costs can also be described as fixed or variable based on their behavior as production volume changes within broad limits. Costs may be fixed, variable, or semivariable as production volume changes in the short run. The short run is defined as a period too short to permit facilities expansion or contraction that might change the overall production relationships. Fixed costs remain relatively constant as production volume is varied over the short run. Examples of fixed costs include fire insurance, depreciation, rent, and property taxes. Of course, if production requirements change significantly, even over the short run, the fixed cost assumption could disintegrate. Variable costs fluctuate directly and proportionately with volume. These proportions remain relatively fixed between certain production limits. Costs such as direct labor and direct material illustrate variable costs. Semivariable costs fluctuate irregularly with volume, often in a stepwise manner. Costs such as supervision illustrate semivariable costs.

Recurring and Nonrecurring Costs

At the beginning of a production program, the contractor expends certain funds to establish the specific capability to manufacture the weapon system or equipment. These nonrecurring costs are one time expenditures and generally include such things as special tooling, special test equipment, plant rearrangement and the preparation of manufacturing instructions. The costs which must be incurred each time a unit of equipment is produced, such as direct labor and direct materials, are the recurring costs. The relative levels of recurring and nonrecurring costs can be evaluated in investment terms since the nonrecurring costs provide the capability to manufacture the equipment with a lower direct labor input per unit. The objective of the contractor and program office should be the definition and achievement of a level of nonrecurring cost that will minimize total cost of manufacture. The investment in nonrecurring costs can be evaluated as a tradeoff decision in that improved tools, test equipment and planning can result in lower recurring cost. The total cost to manufacture is then the sum of the recurring cost plus an amortized share of the nonrecurring cost. As a result of the relationship, decisions on the level of nonrecurring cost should be based on a specific quantity to be produced and rate of production.

Tooling Costs

Preproduction (start-up) costs, such as tooling, will usually be treated as nonrecurring direct charges to the contract. Cost proposals as well as cost analysis should separately identify the amount of preproduction cost included in the program cost estimate.

Tooling is one of the major categories of preproduction cost. As discussed here, tooling refers to special tooling consisting of jigs, dies, fixtures, and factory support equipment used in the production of end items, and does not include machines, perishable tool items, or small hand tools.

The key issue in estimating and analyzing tooling costs is the planned rate and duration of production. The production rate and duration will establish whether there will be hard (durable) or soft (limited life) tooling; whether the tooling will be limited to the production rate required under the proposed contract, or whether it also anticipates production rates of future requirements or the need for surge or mobilization. If tooling is planned in anticipation of future orders, the justification for these plans should be verified. Follow-on purchases should always be analyzed in light of the type and extent of tooling authorized by the government in prior contracts.

There should be an inverse relationship between the amount of tooling and the number of direct labor hours expended per unit of product. It is important that the contractor's tool planning be based on the needs of present and reasonably predictable future purchases. Analysis of tooling cost requires evaluation of material requirements recognizing that many contractors purchase all or a significant part of their basic tooling requirements. Analysis of the labor hours, labor rates, and overhead rates applied to the tool design, fabrication and maintenance efforts is still a significant cost item to be examined, even though passed on to a vendor.

Special Test Equipment Costs

Special test equipment may present a unique problem. While it may be proper to evaluate it in the same manner as jigs, dies, and fixtures, the test equipment may be modified standard commercial equipment. An example of special test equipment might be a microprocessor linked to a printout device so that specific reliability data required by the contract can be accumulated. If the cost of this equipment is large and the equipment has a useful life beyond the contract, the contractor should consider the equipment as a capital investment subject to depreciation over its useful life. While the capitalization of special test equipment may be determined by a policy consistently applied by the contractor, certain contracting rules will govern. The contractor's policy on capitalization should be discussed with the Administrative Contracting Officer (ACO) as to what practices would apply under the circumstances.

COST ACCOUNTING

When costs are estimated, a close look at how a contractor accumulates cost data is an important part of the manufacturing control process. Contractor decisions regarding estimated effort required for manufacturing a system will be largely influenced by the contractor's cost accounting system and the data generated therefrom. Thus, projected effort in such manufacturing process efforts as fabrication, assembly, and other cost categories which in turn can be broken down into specific operations such as welding, setup, windings, etc., must be reviewed from an overall systems standpoint. This section, thus, focuses on cost accounting systems from a manufacturing management viewpoint so that the process of cost incurrence and measurement will be better understood.

Uniformity in Cost Accounting Systems

In the field of cost accounting there are pressures for uniformity and comparability, but most of these arise from special circumstances and they are of less force than appear in the area of financial accounting. This is understandable, since cost accounting is a matter of managerial (internal) information for the most part. When prices are established under less than fully competitive conditions cost data play a large role in contract negotiation and settlement. Under such conditions, the method of cost accounting can make a substantial difference in results, and variations in cost assignment may become a matter for concern.

Every firm has its own characteristics and individuality. These arise from sources that may even be somewhat beyond the control of owners or managers and are useful in adapting to the environment as to markets, products, supply or resources, and other factors. Further, the operation of systems to collect and process data about operations is a part of the task of management, and the outputs of such systems are generally regarded as proprietary to the company.

The idea of standards is used to a considerable extent in all business and accounting data. If cost figures are to be used with confidence, they must meet standards as to their content. Direct costs should be discernible from indirect costs, not by how computations are made or by convenience in making such computations, but by some specified idea of what makes them different.

Until Public Law (PL) 91-379, 15 August 1970, technical evaluators and contracting personnel were required to "decipher" the intricacies of the variations of cost accounting systems existing in the marketplace. PL 91-379 represented a major step toward uniformity in cost reporting. This law, essentially, requires contractors to ensure consistency and uniformity in their cost accounting practices in estimating, accumulating, and reporting cost; and to disclose such practices to the government.

Cost Accounting Systems

The two basic cost accounting systems are the job order cost system and the process cost system. Each can be classified as either a historical cost system or a predetermined cost system, which makes possible four "pure" types of cost systems: (1) the historical job order cost system, (2) the predetermined job order cost system, (3) the historical process cost system, and (4) the predetermined process cost system. Most contractors, however, accumulate both historical data and predetermined data for use in estimating contract costs, and many contractors apply their own variations to the job order cost system and the process cost system.

Under the job order cost system, direct and overhead cost data are accumulated by each contract or order. The contractor's direct employees identify on their time cards the jobs on which they work, and a calculated overhead rate is applied to the direct labor time recorded for each job order. The direct material requirements for each job order can be identified by bills of materials and charged to the particular job order.

The process cost system is used when identifying each individual end product cost is impractical. Under a process cost system, total cost for producing a group of items and the number of units produced are determined for regular accounting periods, and an average unit cost for the period is determined. Under a job order cost system, unit costs are not available until the job is completed; in process costing, average unit costs are determined at the close of cost accounting periods and are available, although a "lot" required by a contract may not even be completed.

Historical Cost Systems

When actual cost data are accumulated after operations have taken place, the cost accounting system is a historical cost system. To prevent distorted projections from historical data, the following should be analyzed in determining expected costs for new products.

- Changes in plant layout and equipment;
- Changes in products, materials, and methods;
- Changes in organization, personnel, working hours, conditions, and efficiency;
- Changes in cost;

- Changes in managerial policy;
- Lag between incurrence of cost and reporting of manufacturing; and
- Random influences such as strikes and weather.

Historical data are used in all cost accounting systems, at least as a base for comparing actual results with predicted results. The accumulation and application of historical data are important ingredients of a reliable cost estimate.

Predetermined Cost Systems

Predetermined cost systems are cost accounting systems in which data about the manufacture of an end product are accumulated before the end product is produced. A contractor using a predetermined cost system uses process and material information about a job to predict the costs for doing that job. When contractors use predetermined cost data, normally these data are substantiated by actual costs identified on previous end products.

CONTRACTOR ESTIMATING SYSTEM REQUIREMENTS

The DOD promulgated new regulations in 1988 requiring major defense contractors to improve the systems they use in estimating costs for negotiated procurements. These regulations apply to defense contractors who, in their last fiscal year, received prime contracts or subcontracts totaling $50 million or more for which certified cost and pricing data were submitted. Partial coverage may apply to contractors and subcontractors receiving contracts totaling $10 million or more.

The regulations stem from hearings of the House Committee on Government Operations, and from General Accounting Office (GAO) and Defense Contract Audit Agency (DCAA) studies in the mid-1980's which indicate that the government is routinely overcharged by 10-15% on negotiated contracts as a result of deficient contractor estimating systems. The regulations define the term "estimating system" broadly, to include not only a contractor's or subcontractor's estimating policies, practices and procedures but also its organizational structure, internal controls and management reviews, among other functions. The new rules required that all contractors have estimating systems that consistently produce "well supported proposals," although the specific requirements apply only to large volume contractors.

The new regulations require that the accounting systems: establish clear responsibility for preparation, review and approval of cost estimates; have written descriptions of the duties of persons involved in estimating; assure adequate personnel training, experience and supervision; provide for consistent applications of established practices and for safeguards to detect errors; and protect against duplication and omissions. Adequate systems will also provide for management review of estimating practices and methods, and for a program of internal reviews, as well as procedures for updating estimates as required. Adequate systems also assign responsibility for review of subcontract prices.

ESTIMATING

Estimating is the method of generating a measure of an amount of work to be accomplished or resources required. It requires systematic study of the activity to be estimated and application of knowledge and skills to form a valid judgment regarding the cost of that work. The resulting estimate provides management with quantitative data for making decisions concerning these programs.

The initial decision that must be made in most estimating situations is the selection of an approach that will yield the most accurate, timely and current cost estimate. The choice of an estimating technique is not solely dependent upon the estimator's preference but is dictated by the estimating environment. The conditions that must be considered are:

1. Comprehensiveness of the statement of work.

2. Availability of pertinent actual cost data and product information.

3. Type of contract, program and category of estimate.

4. Customer and program requirements.

5. Time available for preparation.

6. End use of the estimate.

Estimating Methodologies

Cost estimating is based on interpretations of observed historical factors relevant to the task to be performed which are then projected into the future. These projections can be made in several different ways as discussed below.

The selection of a particular cost estimating method will be guided by the following considerations:

1. Availability of historical data

2. Level of estimating detail required

3. Adequacy of the technical description of the item being estimated.

4. Time constraints

5. Purpose of the estimate

The manufacturing cost estimator should consider using more than one method to generate the cost estimate. One may use a catalog price or an estimate prepared by a specialist to arrive at a cost estimate for a piece of equipment that represents a technological advance over existing hardware. The estimator may compare the cost of an analogous system element with that derived from using a Cost Estimating Relationship (CER). Finally, even if one estimating method will suffice to estimate the cost of an item, the estimator should, whenever possible, use a different estimating method to check on the initial estimate.

Parametric Cost Estimating

Costs of equipment may vary with design/performance characteristics such as weight, speed, or range (cost-to-noncost) or with costs of other items (cost-to-cost). As an example of the latter, the cost of spares may vary with the cost of the prime equipment. The estimator must select the appropriate estimating relationships and consider the availability of statistical information. “Cost-to-noncost” estimating relationships (ERs) are frequently used to estimate costs for equipment items; for example, airframe procurement cost estimated as a function of airframe weight, and turbine engine procurement cost estimated as a function of engine thrust. A variant of this method, a “noncost-to-noncost” ER, may be used to complete a system description, before addressing the cost of the system. For example, the number of administrative personnel required to support a system may be estimated as a function of the number of personnel estimated to operate the system. “Cost-to-cost” ERs may be used to estimate development, investment, and operating costs. For example, equipment installation costs may be estimated as a percent of equipment procurement costs, or replacement personnel training costs as a percent of initial personnel training costs.

Specific Analogies

Specific analogies depend upon the known cost of an item used in prior systems as the basis for estimating the cost of a similar item in a new system. Adjustments are made to known costs to account for differences in relative complexities of the performance, design, and operational characteristics. This is a practical method since many new systems involve essentially new combinations of existing subsystems, major equipment, and components. A specific analogy is frequently used in checking an estimate developed through other methods.

Specialist Estimates

Estimators may obtain an estimate directly from an organization or person having specialized knowledge, for example, an engineer, a program office, training or logistics specialist, or other technical expert. This method is usually applied when ERs and other estimating methods are not available or appropriate, or to verify other estimates. In addition, specialists can often assist the estimator in applying or developing specific analogies. In applying this method, a cost estimator must describe the item to be costed to the specialist. The description can take the form of work statements, technical parameter measures, design specifications, or analogies.

Rates, Factors, and Catalog Prices

Rates are usually based on historical experience plus judgments relative to future price level trends. Factors represent average costs or ratios of costs for designated types of products or services. The estimator can develop factors or obtain them from commercially available or government publications. Catalog prices represent published prices for standard off-the-shelf products or services. When a specific type and quantity of a standard material or component must be identified, this method provides acceptable estimating data.

Industrial Engineering Standards

Industrial Engineering Standards (IES) define and measure, in unit hours or dollars, the work content of the discrete tasks to be performed in accomplishing a given operation or producing an item. IES represent average skills, times, and performance. These standards are used primarily to estimate contractor functional costs such as tool fabrication, manufacturing, and product assurance.

Cost Model Applications

A cost model consists of the estimating relationships and logic used to derive a cost estimate. The unique contribution offered by a model exists within the logic framework which structures the application of the cost estimating techniques. Additionally, the speed of manipulation of computerized models may be advantageous when many design alternatives are being estimated. The cost model might be a checklist of program elements, used to avoid omitting relevant elements from an estimate. Each element would be estimated by the most appropriate cost estimating techniques available. The most complex form might be a computerized model complete with estimating relationships, factors, analogy matrices, standards, and catalog prices.

Trend Analysis

Trend analysis is a quantitative method for relating a variable — direct labor, manufacturing overhead — with time or other measures and represents a common statistical technique employed for both monitoring and estimating costs. Trend analysis, with costs modified to reflect the reasonableness of past, present, and future overhead expenditures, is frequently used to forecast overhead expenses. Similarly, trend analysis is applied to information contained in the various cost reports, where contractually required, or available from internal contractor cost records, to analyze contract performance and forecasting future costs. In this regard, such analysis of cost/schedule trend patterns during the development and production phases of the system life cycle has proven to be one of the most accurate methods of estimating cost of the contract at completion for ongoing programs.

Inflation (escalation) indices are often used in conjunction with trend analysis to ensure comparability of data in different time periods. Inflation/escalation indices are used to estimate the effect on price of the changing value of the dollar over time. In forecasting escalation, the PMO should attempt to utilize indices which reflect the realities of the specific program. The DOD or Office of Management and Budget (OMB) indices should be viewed in light of their past record in predicting actual inflation for the economic activities involved in the individual acquisition program. Where there is a significant difference in the historical data, the PM should attempt to develop program-specific indices which can be presented to the decisionmakers in the Services and DOD to illustrate the potential problems which may arise from use of the DOD or OMB indices.

ESTIMATES BASED ON ENGINEERED STANDARDS

Engineered standards are useful for developing cost estimates once there is a clear definition of the detailed system configuration. Engineered standards are those developed using a recognized technique such as time study, work sampling, standard data or a recognized predetermined time system. These standards provide the benefit of detailed description of required manufacturing operations and provide a base line for the evaluation of actual incurred costs. An industrial engineering standard (IES) is developed as follows:

1. A work statement, set of drawings, or specification is received or developed.

2. Each engineering or production operation required to produce the item or accomplish the designated task is specified.

3. The work stations where each operation will be performed are designated.

4. The kinds of labor and material required to produce the item or accomplish the operation are given in detail.

5. Industrial Engineering studies determine the most economical method of performing each manufacturing operation.

6. An estimated time standard for performing each task is established using time-and-motion studies or predetermined time systems plus experience in performing similar tasks.

7. Labor standards for specific operations may be combined to provide a labor standard for a component, subassembly, major equipment, or subsystem.

8. Labor efficiency factors are used to adjust standard labor hours to actual labor hours. In general, labor efficiency, utilization, or effectiveness measures represent the ratio of standard hours planned to the actual hours expended for a given work operation.

9. Periodically, time standards are adjusted to reflect changes in production methods. Over a period of years some standards become stabilized to such an extent that they become plant, product, or industry standards.

Standard Cost

A standard cost basically represents an expected value of the cost of a system. Standard costs are used as a basis for the development of proposal pricing and also as a benchmark to monitor day-to-day performance and signal when deviations from predetermined policies are occurring. They are based on a defined level of material usage and a standard time for the manufacturing operations. Our focus in this discussion will be on the time component of the standard cost. When directed towards operations involving human performance, the standard time required to perform a task may be defined as the time necessary for a qualified worker working at a pace ordinarily used, under capable supervision, and experiencing normal fatigue and delays to do a defined amount of work of specified quality following a prescribed method. It is obvious from the definition, that on a regular basis, actual shop performance will not reflect the standard time. In most cases, the time proposed by the contractor will be greater than standard time, reflecting either realization factors or efficiency factors representative of the facility and the impact of the learning or manufacturing improvement curve. These two concepts are discussed below. For operations which are machine controlled, the standard time is dictated by the situation of the process and the equipment (including tooling). In most cases machine controlled operations should be relatively consistent and reflect actual costs close to standard. Standards can be developed through job analysis or based upon historical costs, and sometimes are affected by constraints introduced in the contract with the employee bargaining unit.

Variations of Standards

When considering a standard cost, it is important to understand that it is "standard" only within the confines of the system used to develop it. Two different, yet valid, approaches to establishing a standard may yield estimates for the same task differing by as much as 25%. These differences are inherent in the various approaches to establishing standards, but they do not reduce the usefulness of the resultant standard. In looking at a particular contractor facility, the critical issue is that the system used in that facility be internally consistent, i.e., the standard time for a particular task should be independent of the estimator developing the estimate. It is also important to note that the estimate is driven by the particular manufacturing process utilized and the completeness of the description of that process.

Realization Factors or Efficiency Factors

Realization factors or efficiency factors are utilized to reflect the fact that standard performance is seldom maintained during manufacturing. Unpredictable delays do occur and the criteria for standard performances may not be found throughout the facility. For estimating the time that will actually be required, the contractor uses historical relationships between standard and actual times. As an example, a realization factor of 1.5 would indicate that actual time required for a task is 50% greater than standard time. The contractor determines realization factors by recording time actually spent on the specific tasks and comparing that to standard for those tasks. By averaging historical realization factors, the contractor can then determine an appropriate realization factor to use in forecasting actual time requirements.

Some contractors use efficiency factors rather than realization factors. Whether the contractor uses realization or efficiency factors the approach reflects a reasonable method of estimating the time which will actually be required to perform the tasks. There is, however, one major area of concern. There is a reasonably good understanding of “what” realization factors are but “why” is not well understood. It is generally accepted that realization factors may represent shop inefficiencies which could be cured by appropriate management action. A critical issue is to assure that the contractor has taken action to identify and remedy these inefficiencies.

THE LEARNING CURVE

Concept

The learning curve was adapted from the historical observation that individuals performing repetitive tasks exhibit an improvement in performance as the task is repeated a number of times. Empirical studies of this phenomenon yielded three conclusions on which the current theory and practice is based:

1. The time required to perform a task decreases as the task is repeated.

2. The amount of improvement decreases as more units are produced.

3. The rate of improvement has sufficient consistency to allow its use as a prediction tool.

The consistency in improvement has been found to exist in the form of a constant percentage reduction in time required over successively doubled quantities of units produced. This can be seen graphically in Figure 9-2.

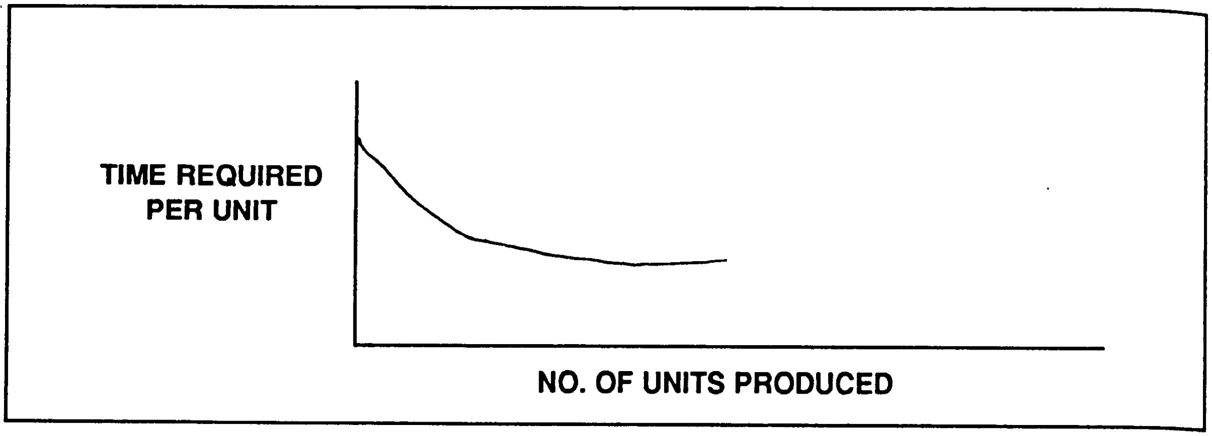

Figure 9-2 Manufacturing Improvement Curve

WORKER LEARNING
SUPERVISORY LEARNING
REDUCTIONS IN CROWDED WORKSTATIONS
TOOLING IMPROVEMENTS
DESIGN PRODUCIBILITY IMPROVEMENTS
IMPROVED WORK METHODS
IMPROVED PLANNING AND SCHEDULING
INCREASED LOT SIZES
REDUCED ENGINEERING CHANGE ACTIVITY
REDUCTION IN SCRAP AND REWORK
BETTER OPERATION SEQUENCING AND SYNCHRONIZATIONS

Table 9-1 Factors Leading to Manufacturing Improvement

Components of Improvement

By its title, the learning curve focuses attention on the worker learning, or job familiarization. This is just one of the components which contribute to the reduction of time requirements. Table 9-1 lists a number of elements which have been shown to contribute to the manufacturing improvement. From Table 9-1 it can be seen that the total improvement is a combination of personnel learning and management action. While some study has been done, there is no general rule concerning the relative contribution of the specific elements. Figure 9-3 illustrates the results of a study by the Air Force Materials Laboratory on the components of learning in a production fighter program. The critical issue is to recognize the role of management in achieving these reductions and to ensure that appropriate management actions are taken.

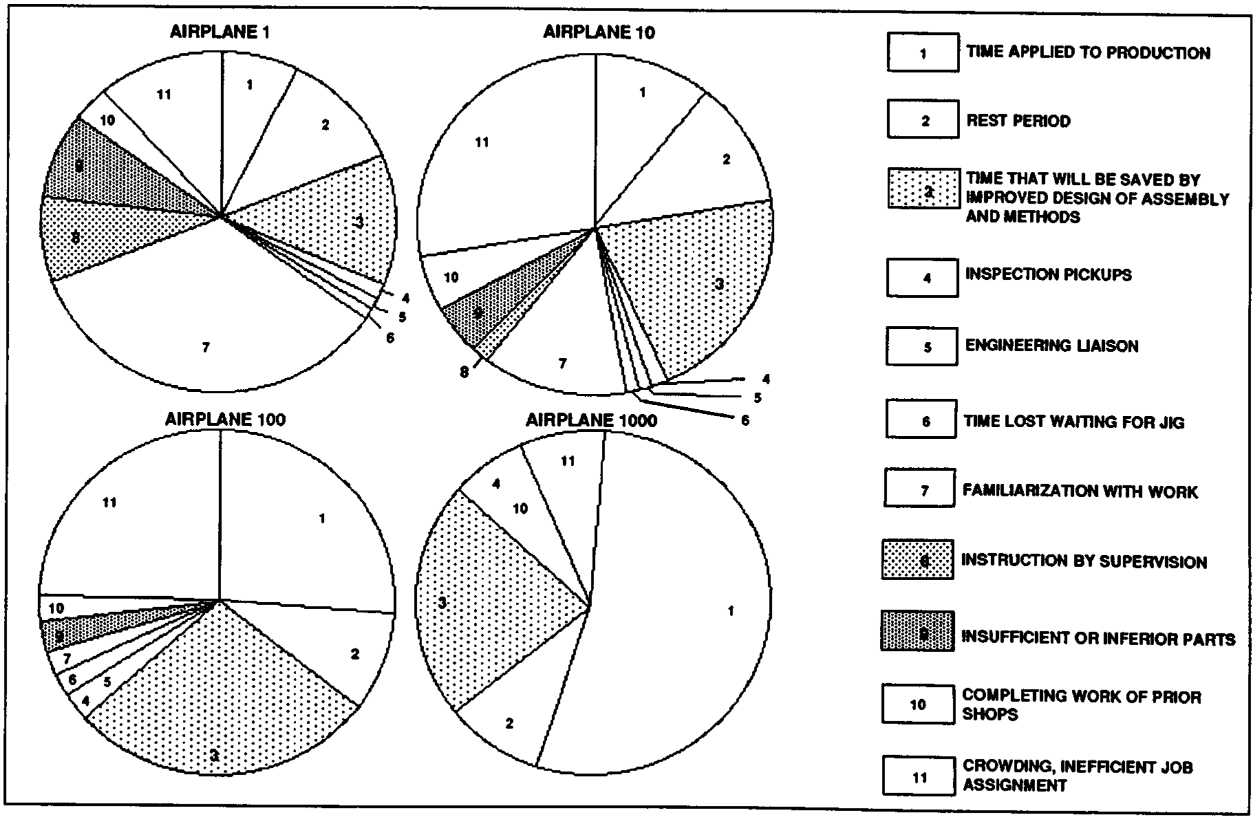

Figure 9-3 Components of Learning

Characteristics of Learning Environment

While learning is found in almost all elements of the defense industry, its impact is most pronounced when certain characteristics are present. The first characteristic is the building of a large complex product requiring a large number of direct labor hours. The second is continuity of manufacturing to preclude loss of accrued improvements during production breaks. The third characteristic is an element of continuing change in the product. This third characteristic can present some problems in analysis using the manufacturing improvement curve.

The historical data on which a company's improvement curve is based contain the effects of an engineering change activity which can be characterized as "normal." During the analysis of the program of interest, changes which are developed need to be evaluated to determine whether they are "normal" and already accounted for by the learning curve, or major changes which must be the subject of a contract modification. The decision needs to be made on the basis of the unique situation involved in the program. This should be done in the context of the nature of the historical contractor activity which was used to develop the learning curve used in the contract negotiation.

Key Words Associated with Learning Curves

To utilize learning curve theory, certain key phrases listed below are of importance:

- Slope of the Curve — A percentage figure that represents the steepness (constant rate of improvement) of the curve. Using the unit curve theory, this percentage represents the value (e.g., hours or cost) at a doubled production quantity in relation to the previous quantity. For example, with an experiecence curve having an 80% slope, the value at unit two is 80% of the value of unit one; the value at unit four is 80% of the value at unit two; the value at unit 1,000 is 80% of the value at unit 500; and so on.

- Unit One — The first unit of product actually completed during a production run. This is not to be confused with a unit produced in any preproduction phase of the overall acquisition program.

- Cumulative Average Hours — The average hours expended per unit for all units produced through any given unit.

- Unit Hours — The total direct labor hours expended to complete any specific unit.

- Cumulative Total Hours — The total hours expended for all units produced through any given unit.

Unit Curve

There are two fundamental models of the learning curve in general use, the unit curve and the cumulative average curve. The unit curve focuses on the hours or cost involved in specific units of production. The theory can be stated as follows:

- As the total quantity of units produced doubles, the cost per unit decreases by some constant percentage.

- The constant percentage by which the costs of doubled quantities decrease is called the rate of learning.

- The "slope" of the learning curve is related to the rate of learning. It is the difference between 100 and the rate of learning. For example, if the hours between doubled quantities are reduced by 20% (rate of learning) it would be described as a curve with an 80% slope.

The difference or amount of labor-hour reduction is not constant. Rather, it declines by a continually diminishing amount as the quantities are doubled. The amount of change over the "doubling" period has been found to be a constant percentage of cost at the beginning of the doubling period.

A labor-hour graph of this data curve drawn on ordinary graph paper (rectangular coordinates) becomes a hyperbolic line. Figure 9-4 pictures the relationship between two variables, units produced in sequence and labor hours per unit. When labor hour figures that conform to the learning process are plotted on log-log paper against the units of production to which they apply, the points thus produced lie on a straight line.

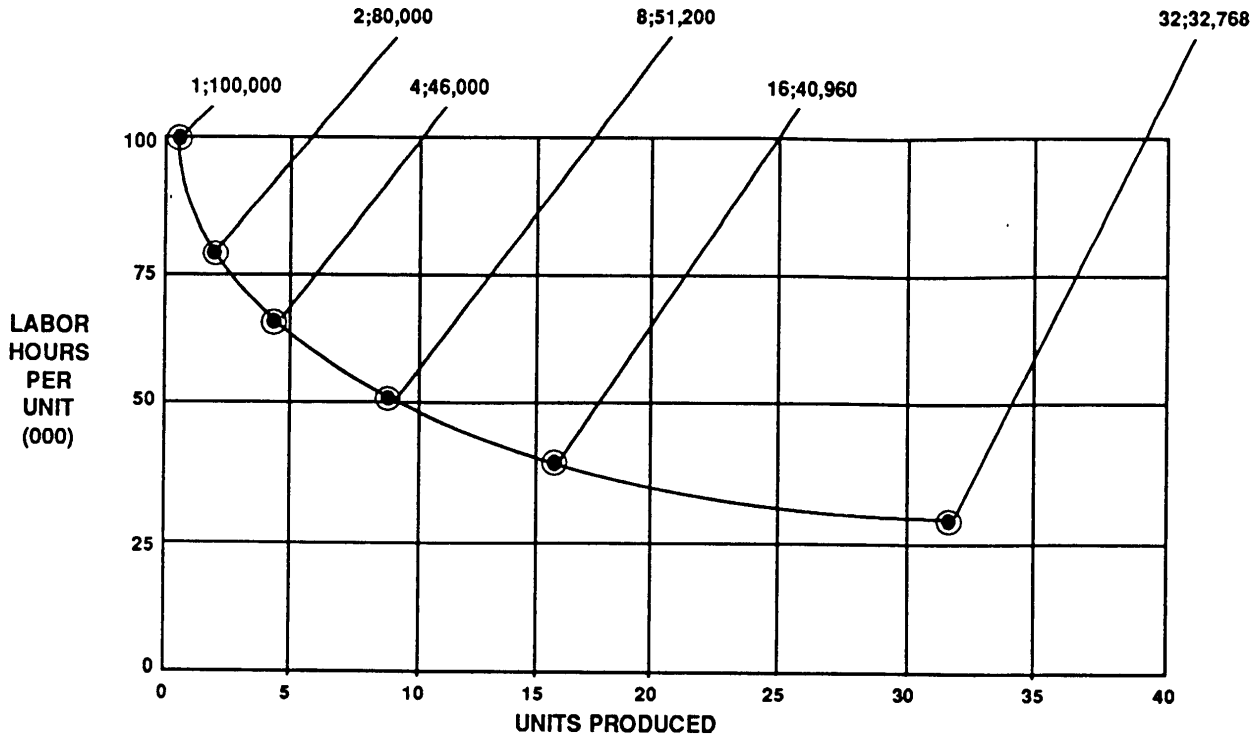

Figure 9-4 An 80 Percent Learning Curve Drawn on Arithmetic Graph Paper

Developing Slope Measures

Research by the Stanford Research Institute revealed that many different slopes were experienced by different manufacturers, sometimes on similar manufacturing programs. In fact, manufacturing data collected from the World War II aircraft manufacturing industry had slopes ranging from 69.7% to almost 100%. These slopes averaged 80%, giving rise to an industry average curve of 80%. Other research has developed measures for other industries such as 95.6% for a sample of 162 electronics programs. Unfortunately, this industry average curve is frequently misapplied by practitioners who use it as a standard or norm. When estimating slopes without the benefit of data from the plant of the manufacturer, it is better to use learning curve slopes from similar items at the manufacturer's plant, rather than the industry averages.

The analyst needs to know the slope of the learning curve for a number of reasons. One is to facilitate communication, as it is part of the language of the learning curve theory. The steeper the slope (lower the percent), the more rapidly the resource requirements (hours) will decline as production increases. Accordingly, the slope of the learning curve is usually an issue in production contract negotiation. The slope of the learning curve is also needed to project follow-on costs using either the learning tables or the computational assistance of a computer.

Selection of Learning Curves

Existing experience curves, by definition, reflect past experience. Trend lines are developed from accumulated data plotted on logarithmic paper (preferably) and "smoothed out" to portray the curve. The type of curve may represent one of several concepts. The data may have been accumulated by product, process, department, or by other functional or organizational segregations, depending on the needs of the user. But whichever experience curve concept or method of data accumulation is selected for use, based on suitability to the experience pattern, the data should be applied consistently in order to render meaningful information to management. Consistency in curve concept and data accumulation cannot be overemphasized because existing experience curves play a major role in determining the projected experience curve for a new item or product.

When selecting the proper curve for a new production item when only one point of data is available and the slope is unknown, the following, in decreasing order of magnitude, should be considered:

—Similarity between the new item and an item or items previously produced.

—Addition or deletion of processes and components

—Differences in material, if any

—Effect of engineering changes in items previously produced

—Duration of time since a similar item was produced

—Condition of tooling and equipment

—Personnel turnover

—Changes in working conditions or morale

—Other comparable factors between similar items

—Delivery schedules

—Availability of material and components

—Personnel turnover during production cycle of item previously produced

—Comparison of actual production data with previously extrapolated or theoretical curves to identify deviations

It is feasible to assign weights to these factors as well as to any other factors that are of a comparable nature in an attempt to quantify differences between items. These factors are again historical in nature and only comparison of several existing curves and their actuals would reveal the importance of these factors.

When production is underway, available data can be readily plotted, and the curve may be extrapolated to a desired unit. However, if production has yet to be started, actual unit one data would not be available and a theoretical unit one value would have to be developed. This may be accomplished in one of three ways:

- A statistically derived relationship between the preproduction unit hours and first unit hours can be applied to the actual hours from the preproduction phase.

- A cost estimating relationship (CER) for first unit cost based upon physical or performance parameters can be used to develop a first unit cost estimate.

- The slope and the point at which the curve and the labor standard value converge are known. In this case a unit one value can be determined. This is accomplished by dividing the labor standard by the appropriate unit value.

Manufacturing Breaks

A manufacturing break is the time lapse between the completion of an order or manufacturing run of certain units of equipment and the commencement of a follow-on order or restart of manufacturing for identical units. This time lapse disrupts the continuous flow of manufacturing and constitutes a definite cost impact. The time lapse under discussion here pertains to significant periods of time (weeks and months) as opposed to the minutes or hours for personnel allowances, machine delays, power failures, and the like.

It is logical to assume that because the experience curve has a time/cost relationship, a break will affect both time and cost. Therefore, the length of the break becomes as significant as the length of the initial order or manufacturing run. Because the break is quantifiable, the remaining factor to be determined is the cost of this lapse in manufacturing (that is, the additional cost incurred over and above that which would have been incurred had either the initial order or the run continued through the duration of the follow-on order or the restarted run).

The S-Curve

The S-Curve is a formulation of the learning curve which has been supported by actual cost experience observed in industry. This S-Curve describes the situation where the initial units in the production cycle exceed the anticipated "normal" learning curve values by a significant percentage and at a relatively low learning rate. This is illustrated in Figure 9-5.

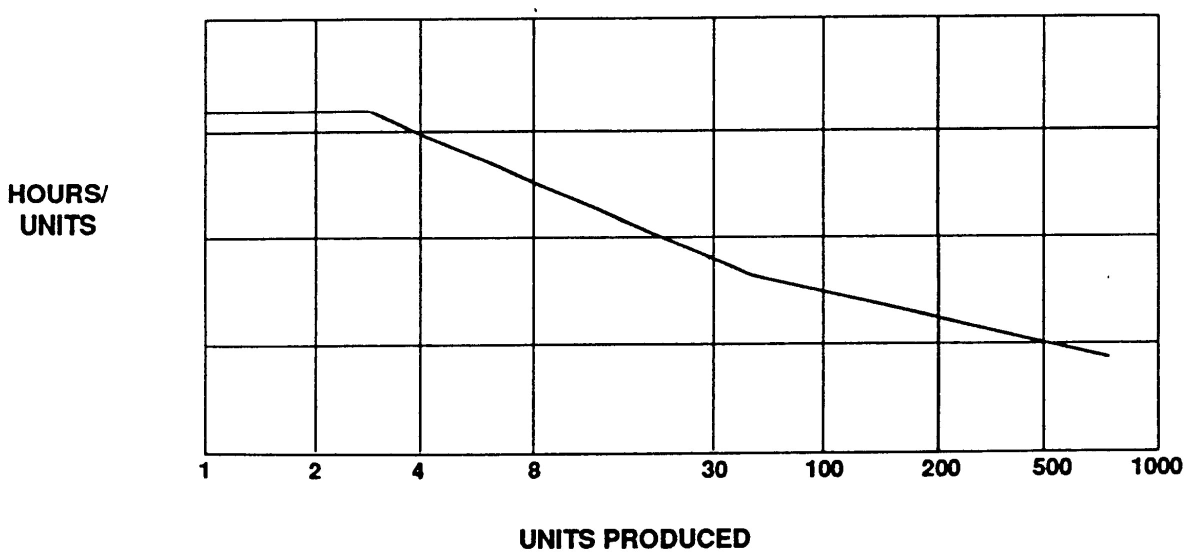

Figure 9-5   An S-Curve Model

As the production cycle continues to produce units of the product, these unit costs begin to drop sharply, actually dropping below the normal learning curve generally anticipated at that point and then begin to proceed at a lesser improvement rate.

This pattern may reflect the fact that during the introduction of a new product, intensive demands are placed upon the entire organization. These demands are the result of frequent design changes and production interruptions causing new requirements for training production and supervisory personnel in new manufacturing techniques and possibly requiring the development of new procedures for production planning and control.

If this situation exists and is not recognized by using an analysis based upon the S-Curve rather than the standard learning curve, the result could be that sufficient funds would not be available during the early part of the program.

If the PMO decides to use the S-Curve approach, Figure 9-5 illustrates a method that could be used for modeling this procedure. The figure reflects an initial period of slow learning, followed by a period of more rapid learning, and then followed by a slower learning level. To use this approach it would be necessary to evaluate the specific company's experience to determine where the break points would occur and the appropriate slopes for the curve segments. This illustration (Figure 9-5) indicates the first break point at unit 3; the actual break point may come much later in the program and some research has indicated that near unit 30 is the most likely point for the first break.

Learning Curves Applied to Standard Times

It should also be recognized that different areas of the contractor operations will exhibit different learning patterns. In a detailed evaluation of the cost to perform, it may be advisable for the contractor and program office to utilize these specific curves (for areas such as assembly, fabrication, etc.) rather than a composite curve summarizing all the differing types of activity within the facility.

When utilizing the learning curve to develop program or contract estimates from engineered standards, we rely on a model such as that shown in Figure 9-6. The time required at standard is reflected by the portion of the learning curve which can be considered to be essentially horizontal. In order to estimate the costs of the early units, such as those to be purchased on the first production contract, three determinations are required:

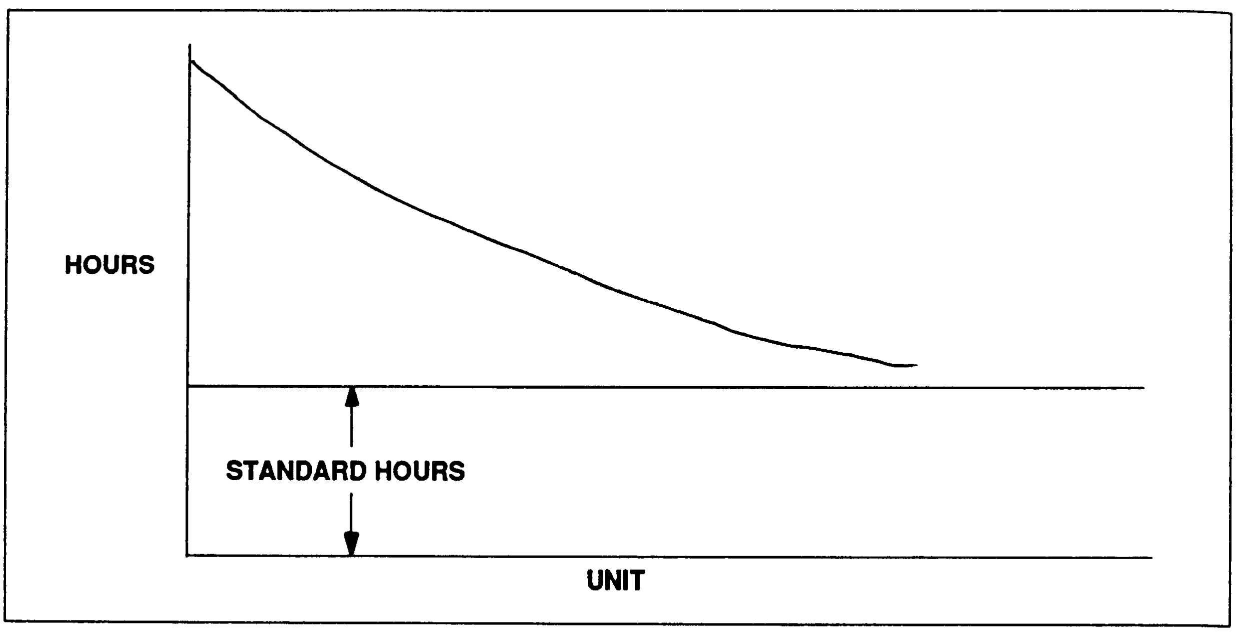

Figure 9-6 Learning Curve

STANDARD 10,000 HOURS 80% CURVE		
STANDARD AT UNIT	FIRST UNIT HOURS	TOTAL HOURS: FIRST 20 UNITS
400	68,810	721,510
500	73,940	775,250
1,000	92,400	968,810

Table 9-2 Cost Impact of Varying Baseline Unit for Standard

1. The hours required at standard,
2. The unit number of which standard is reached, and
3. The slope of the learning curve.

The determinations required in 2 and 3 should be developed based on historical records for the specific manufacturing facility involved and the nature of the manufacturing operations (a high proportion of tasks with machine dictated times tends to appear horizontal at a lower unit number). The potential impact of variation in the unit determined as standard can be seen in Table 9-2. Contractor historical manufacturing data should be reviewed to select the appropriate point for standard.

The appropriate slope for the curve also should be developed from contractor experience. It should also be recognized that the historical rate of learning may not be the most appropriate for the program under consideration.

MANUFACTURING RATE/COST RELATIONSHIP

The rate at which items are completed and delivered is directly related to the manufacturing cost of the program. Generally, higher manufacturing rates will allow for greater economies of scale and result in lower unit cost and lower program cost for a fixed quantity.

The PM must be aware of manufacturing rate characteristics impacting cost. These characteristics include the extent to which the manufacturing process is machine paced, the number of shifts employed or available, and the mechanism by which different rates are accommodated. Each program's manufacturing characteristics will be unique — ranging from low volume, labor intensive to highly automated scenarios. The variety of circumstances encountered might include steady manufacturing rates, breaks in manufacturing, rates buffeted by multinational considerations, extended periods of low rate manufacturing while awaiting improved version approval, and the like.

In evaluating the cost for either a unit or total DOD acquisition program, one of the most substantial impacts has come from inflation. By running a program at an accelerated rate, systems are produced earlier and are subject to a lower inflation effect. Within the context of a specific product/manufacturing environment set, other benefits can be operative. Within many manufacturing facilities, total overhead is relatively insensitive to changes in manufacturing rate. Increases in the rate thus provide more units to which those costs can be applied within a specific area. The facility also benefits from some of the economies of scale such as:

— Increased specialization
— Greater opportunity for tooling
— Increase use of shop aids
— More intense facility usage

Figure 9-7 defines some of the general boundaries for the rate decision. If the program has a high level of technical risk, it is generally better to hold to lower rates until the risk is reduced and the value of the manufacturing output is known. There is a boundary shown on the right side of the figure relating to the issue of technological obsolescence. If the rate is held too low, it is possible that units produced at the end of production phase of the program will represent technology that is obsolete in terms of its ability to meet the defined threat.

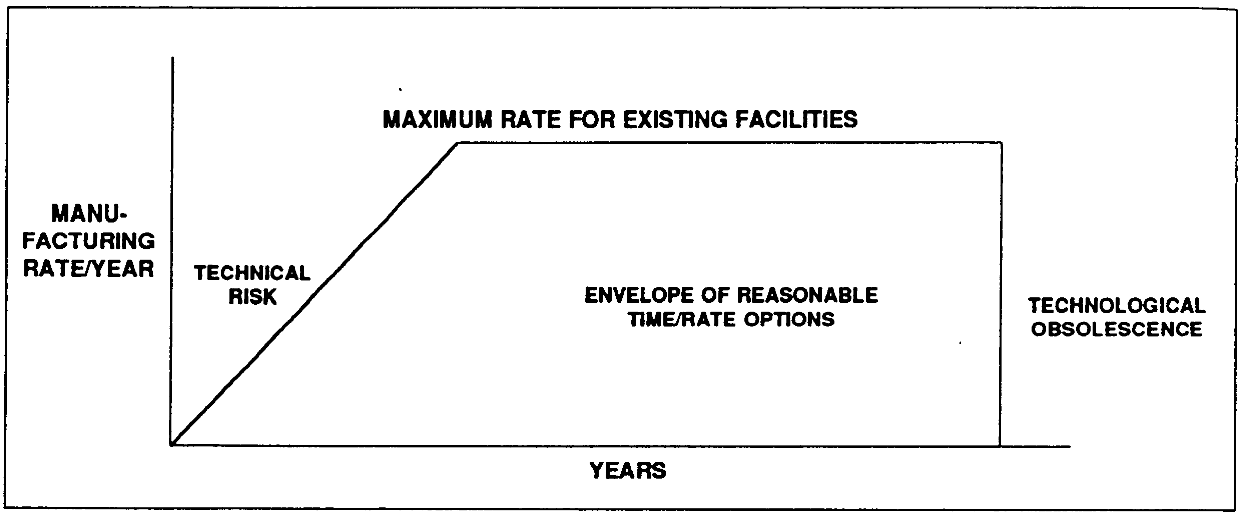

Figure 9-7 Manufacturing Rate Options

There also tends to be a maximum rate which can be supported by the defined manufacturing facility. These rates are rarely reached in most DOD programs except for short periods. This is due to the effects of the learning curve on the manufacturing environment.

DESIGN TO COST

The term "design to cost" means the management and control of future acquisition, operating and support costs during the design and development process under established and approved cost objectives. A design to cost goal is a specific cost number (in constant dollars for a specified number of systems at a specified production rate) established as early as possible in the acquisition process, but not later than the time of entry into the full-scale development phase.

The decision to apply design to cost principles to most defense system programs was made in the light of hard realities of likely future levels of DOD budgets and the ever increasing costs of unit acquisition, manpower and support.

In almost every area in the projected DOD budget the estimated costs of new systems substantially exceed the ability to buy them in needed quantities. The cost of manning and maintaining these systems is also increasing.

Commercial Practice

In industry, design to cost is not a new concept. It has been used by many manufacturers of commercial products, ranging from radios to automobiles. Managers and engineers in commercial industry are generally well aware of the item cost target for a manufactured item, which must be achieved if the product is to be competitive. Cost goals, compatible with projected markets, are regularly established as design objectives.

As the design evolves, anticipated production costs are fed back to designers and managers to inform them of progress toward the production cost goal and to identify areas needing corrective action. When required, nice but less essential features may be reduced or eliminated to achieve the cost goal.

DOD Experience

In contrast, DOD had traditionally operated under the assumption that defense systems and equipment, on an individual basis, must have the best performance that technology can provide — cost being, at best, a secondary consideration. This practice has frequently resulted in a reduction in the number of items to be purchased, and the advanced technology equipment has frequently had a lower field reliability than desired. Extensive and costly modifications and delays in upgrading the operational capability were not infrequent.

Because of the emphasis on performance, the subsequent costs of manufacturing, operation and support were not emphasized in the design and development of defense systems and equipment. Consequently, information obtained concerning such costs during the design phase was seldom fed back to development managers and design engineers. In addition, there was little motivation for designers to consider future manufacturing, operation and support costs, and to direct their efforts accordingly; yet the original requirements and the subsequent engineering design are the most important factors driving such costs.

The application of the design to cost concept attempts to recognize these economic and motivational realities. It recognizes that the "best" system design is not necessarily achieved by maximizing individual unit performance only; rather, it is a function of need, performance, life cycle cost and quantities needed to address the threat. It recognizes that actions in the engineering budget area significantly affect budgets in other areas; and that all of these trade-offs must be made within realistic total resource constraints.

SHOULD COST

Should cost reviews provide an effective method for assessing contractor cost proposals. The in-depth analysis used in the should cost approach provides a basis for clear understanding of the details of contractor operations. These details can be used in making a comprehensive evaluation of proposal costs. The evaluation can then be used to reduce the cost to the government of the systems and equipments which are required to meet DOD's worldwide operational commitments.

Should cost evaluations are cost estimates done by the government and provided to buyers and contracting officers as a tool for use in price negotiations. They consist of an engineering analysis, associated drawings, and detailed reviews of all related cost elements which, together, represent an independent estimate of what an item should cost.

A should cost review uses an integrated team having a variety of skills and experience to conduct coordinated, in-depth cost analysis at a contractor's plant. These reviews are normally accomplished on programs requiring DAB approval. The purposes of the review are to identify inefficient and uneconomical contractor practices, to quantify the impact of these practices on system cost, and to use the findings to develop a realistic price objective.

The performance of a should cost analysis represents a significant investment by the government in time, resources and personnel. Its use is justified in instances where the government anticipates a major return on investment. This return is manifest in the negotiation of contract cost objectives which have imbedded in them attainable improvements in contractor economy and efficiency. The should cost approach is most attractive for application to production contracts with large dollar expenditures and a potential for substantial follow-on, with no competition, and with some production effort already completed.

In this environment, the should cost review offers an outstanding opportunity for substantial benefits. Attaining these benefits requires that a team of highly qualified individuals, who represent a large number of disciplines, be assembled to make an in-depth evaluation of the contractor's proposal. This evaluation goes beyond the normal cost analysis in which the expected cost outcome of a planned series of contractor actions is validated. In the should cost approach those proposed actions which form the basis of the proposal need to be examined in a critical fashion to identify and challenge inefficient or uneconomical practices within the contractor's management and operations. As these weaknesses are identified, their cost impact is quantified and reflected in the government negotiation objectives. The objectives must then be supported with a clear description of the basis for the positions taken, the rationale underlying the positions taken, and a description of contractor actions that can improve or eliminate inefficient and uneconomical practices.

In a report issued in September 1985, GAO reported that when used, should cost analysis was an effective tool in reducing contractors' proposed prices. GAO concluded there were inadequacies in DOD should cost policy that resulted in under-utilization of the should cost concept.

GAO has recommended that OSD revise its policy to require that the Military Departments perform at least one should cost analysis early in the production cycle for each major program and has better defined the conditions that identify the applicability of these pricing techniques. These recommendations were implemented through changes to the Federal Acquisition Regulation and the DOD Supplement. Congress has passed legislation which closely parallels DOD should cost audits.

Normally, the manufacturing management group supporting the program manager is tasked to evaluate the manufacturing material and labor costs.